SMOS Data Assimilation Study
Phase-2 Progress Meeting 3

Date and location of the meeting: 27 March 2012 at ECMWF.

Participants

ESA: Matthias Drusch (MD), Susanne Mecklenburg (SM)
ECMWF: Joaquín Muñoz Sabater (JMS), Patricia de Rosnay (PdR), Lars Isaksen (LI), Jean-Noël Thépaut (JNT), Clément Albergel (CA), Gianpaolo Balsamo (GB), Mohamed Dahoui (MD)
UKMO: Yaswant Pradhan (YP).

Agenda

10:45-11:45 SMOS mission status: Susanne
11:45-12:00 Project status (1. and 2. contract), deliverables, delays, payments, etc.
12:00-12:30 SMOS monitoring and operational implementation plans: Joaquín
12:30-13:00 CMEM v4 and BUFR2GRIB software: Patricia
13:00-14:00 Lunch
14:00-14:30 CMEM calibration and SMOS bias correction: Patricia
14:30-15:00 Use of SMOS data in the EKF (implementation): Joaquín
15:00-15:30 SMOS + Hydrology DA study - status and synergies: Matthias
15:30-16:00 Status at UK Met Office and discussion
16:00-16:15 Coffee break
16:15-17:00 ECMWF- ESA internal discussion

Presentations

The presentations are available under “Workshops” at:
http://www.ecmwf.int/research/ESA_projects/SMOS/conf/smos_conf.html

General information

This meeting is the third progress meeting of the second phase SMOS data Assimilation Study between ESA and ECMWF. Progress meeting reports of the first phase and second phase project are all available at: http://www.ecmwf.int/research/ESA_projects/SMOS/esa/index.html
**SMOS mission update (SM)**

SM presented an overview of the current SMOS mission status. Concerning data availability and latency, the NRT product is delivered in 84.6% (84.2% in Q4/2011) of the cases since sensing time within the requirement of 165 minutes. The second reprocessing campaign of Level 1, Level 2 soil moisture and ocean salinity was completed the first week of March 2012. The reprocessed NRT conversion has also been completed and the data set, covering 2010-2011, has been sent to ECMWF (and received on the day of the meeting). An issue in the data over the Arctic area (at North of 72 degrees N) was found in the level 1 data set, so NRT data will be released with disclaimer in the documentation file. This issue only concerns sea ice area in the Arctic, it was checked with ECMWF and it does not affect ECMWF activities.

The SMOS NRT light product is now operational at ESA. Validation of the NRT light product and the NRT processor was completed by 12 February. ECMWF also collaborated in the quality control exercise. The processor was deployed in the DPGS at ESAC a week before this meeting. Transfer tests with UKMO have been completed and UKMO will distribute the NRT light product via a dedicated ftp site, making it accessible to further operational agencies. Data transfer to the initial list of recipients has been tested and test data have been made available to Canada (CMC), NOAA NESDIS, NRLMRY. Further links to CPTEC (Brazil) and NASA are ongoing. There is a need to clarify data policy issues and formalise it between ESA-UKMO mutual tasks (i.e. summarise tasks, no exchange of funds, best efforts basis).

Concerning RFI, many sources have been switched off in the past year. Canada has switched off 11 RFI sources, US has switched 13 RFI sources off and after some actions taken by the Chinese authorities, 32 RFI sources have disappeared in China.

SM emphasized that ESA's Earth Observation Envelope Programme is coming up for renewal end of 2012, and that October 2012 is the end of the SMOS nominal lifetime. In November 2012, the ESA Ministerial Council will make a decision about funding for the next 5 years. A strong case is required to receive sufficient funding for continuing the mission, based on results using SMOS data. So, it is crucial to show results from the ECMWF SMOS data assimilation experiments. The assimilation of SMOS data as an application to improve forecasting models is thought to be a pre-requisite for a potential follow-on mission. The decision on a follow-on contract could be based on achievements of the data assimilation study. Several milestones will allow to present and to communicate results, in July (IGARSS), September and October 2012.

**Project status**

PdR presented the current status of the ECMWF SMOS project (see Figure). WP 1500 (CMEM maintenance) and WP 2200 (validation Data Base) were completed. WP 1100 has taken a substantial amount of time in order to keep the update with new cycles. WP 2000 (data Assimilation) relies on the technical implementation of SMOS data within the ECMWF SEKF. This task was delayed due to some technical issues in the handling of satellite data in new cycles, but as well as WP 1400 (Bias Correction), is well advanced as presented by JMS and PdR (see details in the following sections). Given the needs of obtaining significant results, WP1400 and WP2000 are priority compared to WP2100 and WP2300.
### ESA SMOS Project at ECMWF

**Project Phase-II (28 Months):**
- 01 October 2010 - 31 January 2013
- 11 WPs (13PM ECMWF; 28 PM ESA)

<table>
<thead>
<tr>
<th>WP</th>
<th>ECMWF Funding (OD+RD)</th>
<th>ESA Funding (Joaquin)</th>
<th>Task</th>
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<tr>
<td>WP 1000</td>
<td>1 pm</td>
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<td>Coordination ✓</td>
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<td>WP 1100</td>
<td>2 pm</td>
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<td>WP 1200</td>
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<td>WP 1300</td>
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<td>WP 1600</td>
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<td>WP 2100</td>
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<td>Validation data base ✓</td>
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<td>WP 2300</td>
<td>3 pm</td>
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<td>Hot spot analysis</td>
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**Colour code:**
- To do
- Ongoing
- Done

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### ESA SMOS Project at ECMWF

**Status in March 2012**

![Timeline diagram showing project milestones]

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Figure 1: Project WP completion status (top) and schedule (bottom).
**Monitoring of SMOS data (JMS)**

JMS presented the current status of the monitoring suite and the expected future updates. The 15th November 2011 a new monitoring suite substituted the old one, using the last version of the operational IFS cycle cy37r3. The transition between both suites took place smoothly and it had a very small (positive) impact on the global statistics. In addition, the new suite has the big advantage of being very cheap compared to the previous one, as it only uses SMOS data as the only source of satellite data and it does not need to run the full 4DVAR atmospheric analysis and surface analysis. In this way the NRT monitoring is almost guaranteed in normal conditions of the supercomputer usage.

An important update for cy38r2 will be the integration of SMOS monitoring into operations, which will avoid any delay into NRT statistics by any reason. Also, the recent implementation of the RFI flag into the NRT BUFR product will be used to mask also grid points suspicious of being contaminated by RFI. This will make it possible to focus the monitoring activities only in areas potentially clean of RFI. Finally, CMEM will also be updated with the last version.

JMS also presented a few results of the monitoring suite, many of them included in the last monitoring report delivered to ESA. They show the strong influence of RFI, but also snow and ice covered areas in the statistics. A future update will remove these areas. Over oceans, at current only the statistics about brightness temperatures are interesting, as the modelled emission over oceans is not accurate yet.

**CMEM maintenance and BUFR conversion software (PdR)**

PdR presented activities conducted for WP 1500 (CMEM maintenance) and first part of WP 1400 (Bias Correction) that focused on the development of a BUFR conversion software.

It is crucial to use the same version of CMEM for Bias Correction (conducted offline) and for monitoring and assimilation (in the IFS). So, in contrast to the schedule originally defined for the project, WP 1500 (CMEM maintenance) had to be completed before the BC (WP1400), as shown in the updated project schedule in Figure1. CMEM version 4.0 was released on 29 February 2012. It includes the following model developments and fixes:

- A third vegetation configuration (Ecoclimap, TESSEL, H-TESSEL), combining LAI variation and TESSEL vegetation table.
- Roughness parameter for coniferous forest in vegetable.F90 is now equal 1.2 according to Grant et al., 2007.
- Effective temperature computation revised to fix a bug in the Holmes et al 2006 parameterization.
- Input/Output bug fix concerning the output of the diagnostic grid box averaged effective temperature.
- Fix in the atmospheric contribution when Liebe's model is used.

CMEM V4.0 was tested for all Input/Output configurations (GribAPI, GRIBEX, NetCDF, and ASCII). CMEM v4.0 is not bit identical to the previous version (CMEM v3.0), so the sample of Input/Output files was updated and made available on the web page. CMEM fixes were made possible thanks to constructive collaborations with CMEM users. In particular Valentijn Pauwels (Ghent University) and Gabriëlle De Lannoy (NASA/GSFC) gave useful feedbacks concerning effective temperature parameterisation and roughness and vegetation parameters.
The list of modified routines (17 routines) compared to the previous version of CMEM, and the documentation was put available together with the source code and sample Input/Output files at the ECMWF SMOS web page (WP1600):
http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_source.html

For Bias Correction (BC), the SMOS data has to be matched to the ECMWF simulated brightness temperature, so it needs to be available in a format compatible with the IFS output (data on a Gaussian Reduced grid in GRIB format). Therefore the first step of the bias correction work was to develop a BUFR decoder that converts SMOS data into GRIB files. The BUFR decoder is to be used for any offline activities. Offline activities support developments for monitoring and data assimilation. The BUFR decoder gives the SMOS NRT product a format which can be used in any context and compared to model outputs files or ground data (e.g. GRIB, ASCII).

The BUFR2GRIB converter converts BUFR file to GRIB using spatial averaging requested when interpolating BUFR data to regular Latitude-Longitude grid. For 6h periods, the data size decreases from about 2.0 GB for the BUFR files to 0.8 MB for TB data in GRIB at T799 (for two fields TBxx and TByy).

The first reprocessed data set (for 2010) was converted into GRIB using the BUFR2GRIB converter. The SMOS GRIB files are being used at ECMWF for CMEM calibration, SMOS bias correction and scientific studies. It is also relevant to easily check and map the SMOS data, including TB and additional information such as flags, RFI, Faraday and Geometric angles. PdR showed SMOS data content for March 2012, after ESAC implemented the SMOS NRT processor version V505 (RFI flag activated) on 7 March 2012. She showed that the snapshot overall quality flag seems unrealistic since entire orbits are flagged as “degraded or corrupted by missing ADF”, while the TB values are reasonable. Concerning RFI, two bits are used in the SMOS product information flag:

- Bit-1 indicates “Pixel is affected by RFI effects as identified in the AUX_RFILST or it has exceeded the BT thresholds”
- Bit-4 indicates that “Measurement is affected by the tails of a point source RFI as identified in the AUX RFI list (tail width is dependant on the RFI expected BT defined in the AUX RFILST)”

Bit-4 is activated, however it does not report any flagged data.

Bit-1 shows RFI in Europe and in Asia. Most RFI affected areas are located on the side of the swath so mostly in the EAF0V data. AFOV is much less affected by RFI than EFOV. She showed that using basic quality check (radiometric accuracy), filtering range of BT and using only AFOV data allows filtering out lots of RFI affected data. The RFI flag is however useful to filter out RFI that passed the basic quality checks.

The converted GRIB files are also useful for scientific investigations and support to model developments. PdR presented results of CMEM simulations that she performed using as input a set of offline H-TESSEL runs conducted to evaluate the new bare soil parameterization developed by GB. The new bare soil parameterization leads to a sensitivity of about 15K in simulated TB. CA is using these results together with comparison of simulated and observed SMOS TB GRIB files in a short paper that is under preparation.
CMEM Calibration and Bias correction

PdR presented WP 1400 (Bias Correction) activities. Bias Correction is being conducted in several steps:
- BUFR decoder development to be used for offline activities which produces a product in a format able to be used in any context (e.g. GRIB, ASCII)
- CMEM Offline simulations for different configurations of the microwave emission model
- CMEM Calibration (best configuration) based on 1 angle (40°)
- Bias correction (several angles) based on best CMEM configuration.

The first four steps were completed. The BUFR converter was developed and successfully used to convert in GRIB the first reprocessed SMOS data set (available for 2010). This data set was produced at ESAC using processor V300, so it does not include the RFI flag. The reprocessed 2010-2011 data with V500, includes RFI flag, it will be used instead as soon as possible.

CMEM offline simulations were conducted using 18 different configurations of the CMEM:
- 3 Dielectric models (Wang, Dobson, Mironov)
- 3 Vegetation opacity models (Jackson, Wigneron, Kirdyashev)
- 2 Roughness models (Wigneron, Choudhury).

CMEM calibration was conducted at 40 degrees incidence angle for 2010. The best CMEM configuration is chosen based on best correlation and minimum RMSD with the SMOS data.

CMEM simulations were conducted using input from H-TESSEL forced by ERA-Interim simulation (soil moisture, soil temperature, air temperature). So it is based on up to date H-TESSEL (including bare soil evaporation and LAI cycle).

For both calibration and CDF matching, data quality control was conducted including masking out:
- Slope index larger than 4% (use ECMWF sub-grid scale orography)
- Snow covered areas
- Freezing temperature areas.

CMEM TB was rotated to the antenna frame using both the Geometric and Faraday angles (Converted in GRIB by the BUFR2GRIB converter). Wetland areas were already masked (when water fraction is larger than 5%) in SMOS GRIB files.

For each of the 18 CMEM configurations, simulated TB and observed SMOS TB were compared. Comparison includes for each month of 2010: mean bias, RMSE and Mean value of time series correlation for each grid point. Results show that using the Choudhury parameterization for the soil roughness (as currently used for monitoring) systematically leads to negative bias (OBS-Model). This indicates that Choudhury’s parameterization overestimates simulated TB. In terms of correlation, Wigneron’s roughness parameterisation consistently improves correlation values between simulated and observed SMOS TB. Simulated TB is very sensitive to the choice of roughness and vegetation parameterizations. The best parameterization for the vegetation optical depth is Jackson. This result is interesting since the previous ALMIP-MEM study showed that Kirdyashev was the best parameterisation for C-Band (evaluated against AMSR-E data).

The overall best configuration is found to be Mironov for the dielectric model with Wigneron for the soil roughness and Jackson for the vegetation opacity. Results were obtained based on 06UTC data. CMEM calibration will be completed with all the orbits. However, it should be noted that parameters have not been optimized.
Once CMEM calibration is completed, based on 40 degrees incidence angle, CMEM best configuration will be used for the bias correction at several incidence angles. The overall WP will be completed by the end of July 2012.

**Use of SMOS data in the EKF (JMS)**

JMS presented the main points in the implementation of SMOS data within the ECMWF version of the Extended Kalman Filter. As pointed out by JMS, this task was very technical and included lot of work with the code. This task is completed and the next step is the implementation of the bias correction, which will completely let the system ready to assimilate SMOS data.

Unfortunately implementing SMOS data in the SEKF has been a challenging technical task too and it has taken longer than expected. There are several reasons for that. Firstly, the operational SEKF is decoupled from the atmospheric 4DVAR, whereas SMOS monitoring is (as it is done for all the other source of satellite data) produced in 4DVAR space. Specifically for SMOS data, the SEKF needs information computed in 4DVAR space, in particular the SMOS observations, which are active for assimilation and which are evaluated within the monitoring routines. This information is somehow ‘lost’ in SEKF space and it has to be reproduced again in order to guarantee that only the SMOS grid points closer to the ECWMF grid are assimilated, and only one per polarisation and angular bin. Secondly, the monitoring routines run per model time step, whereas the SEKF equations are solved per grid point and considering the entire assimilation window as a unique step. This created a problem of compatibility. JMS showed two possible strategies to solve this problem and he decided to use the safest one, which involves repeating for each control variable a series of tasks already done in 4DVAR space. However, these tasks are very cheap and then they do not have any impact on memory or computing time. Thirdly, the transition from cy36r4 (where the implementation was started) to cy37s was very problematic due to very technical reasons, which needed the collaboration with scientists of other sections. Fourth, two ODB important bugs very difficult to spot produced a cluster of observations systematically disappear of memory. Finally, some minor bugs were also corrected which halted some active observations to be assimilated in arid and semi-arid areas. JMS also emphasized the fact that testing and debugging took lot of time as the system of priorities and queues used at ECMWF does not favour data, which takes lot of memory, as is the case for SMOS.

Finally, JMS also pointed out that even if the technical part is at the final stage, there are still a lot of variables and parameters (variance-covariance error matrices, perturbations of the control variables to assure linearity of the observation operator, thresholds for quality control checks, etc.) to be fine tuned up in order to get the most of the SMOS data information in assimilation experiments.

**Status at the UKMO (YP)**

YP presented UK MetOffice activities. ESA push the Level 1 data to the UKMO via ftp; no use of GTS networks has been made as yet. UKMO has been providing data to:

- NESDIS via ftp push
- CMC via ftp collect
YP presented results of the comparison between SMOS Level2 soil moisture and UKMO soil moisture. The UKMO FC model runs on a N512 grid (~25km). The MOSES Land Surface Model is used to represent surface processes. Soil moisture analysis relies on a nudging scheme and ASCAT soil moisture data is assimilated in operations. Soil moisture is represented in the LSM on four discrete layers from surface to 3m depth, with the first layer being 10cm thick. The SMOS data quality control was based on SMOS DQX (Data Quality Control) values lower the 0.04 m$^3$m$^{-3}$. Soil moisture data from the SCAN network, providing local measurements, were used together with SMOS and UKMO soil moisture data to inter-evaluate the three products errors using the triple collocation method. Results indicate lowest errors for SCAN ground data (0.025 m$^3$m$^{-3}$). The SMOS product and the UKMO soil moisture analysis errors are 0.047 m$^3$m$^{-3}$ and 0.037 m$^3$m$^{-3}$, respectively. These results show that the agreement between SMOS and ground data and UKMO model is pretty reasonable. SMOS data tend to give drier soil moisture than ground and model data, specially over forested areas. The product quality seems to be better from November 2011 after the update of the SMOS processor. The SMOS data will be used at the MetOffice to evaluate the EKF under development.

**ESA SMOS activities**

MD presented the global picture of the SMOS activities at ESA. SMOS Level 1C is used by:

- SMOS + Permafrost project. This project is expected to lead to a new product of soil freezing depth, provided at global scale (FMI).
- SMOS + Neural Network study. CESBIO will train the neural network (using ECMWF or other). This project may result in new Level 2 soil moisture products, e.g. a NRT soil moisture product based on the NRT light product and the neural network algorithm. In addition, SMOS and ASCAT data will be used to analyse the information content in both observation data sets and the potential of combined retrievals.
- SMOS + Hydrology. University of Gent is the PI of this project. They use VIC and CMEM and an EnKF. The objective of the project is to evaluate the impact of SMOS on flood and drought forecasts.
- SMOS Sea Ice. Led by University of Hamburg, a novel sea ice thickness product is being developed.
- VWC and Vegetation optical depth products are being evaluated under a research fellowship.

The SMOS NRT product is used by:

- ECMWF so far. Sea ice team might be interested. A Root zone Soil Moisture product will be produced (Level 3 product).

NRT light is used by:

- UKMO, CMC, BoM, NESDIS

The BUFR converter is potentially very useful to develop a new ultra-light SMOS TB product. Such a product provided to the users in GRIB, with each file less than 1MB would be highly relevant for the SMOS users’ community. For the next contract, starting from February 2012, ESA is highly interested in having a WP dedicated to the operational implementation of the BUFR
converter, for ECMWF to produce the SMOS ultra-light product in NRT in GRIB. This was discussed later in the day in the ECMWF-ESA internal discussion on the contract continuity for 2013-2014.

**ECMWF-ESA internal Discussion**

The current contract between ESA and ECMWF, “SMOS Data Assimilation Study, Phase-2”, is coming to an end on 31 January 2013. A time slot was dedicated to ECMWF-ESA discussions (SM, MD, PdR, JMS, LI, JNT, CA) in order to define a possible continuity of the SMOS activities at ECMWF from January 2013.

SM indicated that a maximum two-year contract could be discussed based on intermediate funds. So, it would be independent from the EOEP-4 decision in November. The contract would go through direct negotiation as the current contract.

The list of proposed WPs was prepared prior to this meeting and proposed as follow:

**ESA Funded:**
- Technical WP (DPGS, BUFR specification, QWG) 2pm
- Reprocessing and Root Zone SM 4pm
- Monitoring 4pm
- Ultra light product 4pm
- EDA/EPS perturbations calibrated using SMOS 10pm

**ECMWF funded:**
- Improvement of the DA system (B matrix, further impact, FSO)
- Offline SMOS DA
- Support reanalysis activities (ERA-SAT)
- SMOS Explorer transition (link SMAP)

It was agreed that MD, JMS and PdR will prepare the statement of work early this summer. The ultra-light product should be discussed in the SMOS QWG end of May.

**Next PM meeting will take place in September 2012.**